Engineering Structures 141 (2017) 292–302

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Performance and degradation of sliding steel friction connections: Impact of velocity, corrosion coating and shim material

G.W. Rodgers [a], J.G. Chase [a], R. Causse [a], J. Chanchi [b,c], G.A. MacRae [b,*]

[a] Dept. of Mechanical Engineering, University of Canterbury, Christchurch 8140, New Zealand
[b] Dept. of Civil Engineering, University of Canterbury, Christchurch 8140, New Zealand
[c] National University of Colombia, Manizales, Colombia

ARTICLE INFO

Article history:
Received 4 September 2016
Revised 10 February 2017
Accepted 28 February 2017

Keywords:
Buildings
Connections
Corrosion
Friction
Low damage
Velocity
Steel

ABSTRACT

It has become increasingly necessary to develop systems to decrease the impact of earthquakes by protecting people and mitigating resulting structural and economic damage. The Asymmetrical Friction Connection (AFC) or Sliding Hinge Joint (SHJ) has been intensively tested. It efficiently dissipates energy with almost no damage. However, its nonlinear mechanics have not fully been characterised.

In this study, the AFC mechanism is fully modelled and parameterised using non-linear modelling. Menegotto-Pinto models of device behaviour, including added velocity dependence, are validated against a series of experimental tests. These SHJs are modelled for several shim (friction sliding surface) materials, as well as with and without corrosion resistant coatings.

The non-linear models developed accurately capture the experimentally observed nonlinear mechanics. The impact of shim material and corrosion coating on resistive force and velocity dependence are quantified. In particular, corrosion coatings create negative velocity dependence from a positive dependence without the coating. The overall modelling approach is suitable for use in a wide range of similar dynamic systems. Thus, the results also validate the overall modelling methods and the approach presented.

1. Introduction

The recent series of large earthquakes that have struck New Zealand, Japan and Chile have again highlighted the potential for death, damage and downtime due to large seismic events. Significant structural damage in the beam/column connections of moment frames, can result in significant downtime and economic loss, even if the structure is reparable. In particular, the displacement caused by a large earthquake dissipates significant energy due to the sacrificial design approach used to preserve life safety, but can equally degrade structural integrity and render a structure unusable. It costs time and significant economic resource to rebuild a city after a major earthquake, and even more to regain lost prosperity of the region. This clarifies the need for focus on emerging trends towards mitigating damage in addition to providing life safety.

Consequently, many researchers are trying to find mechanisms to increase structural life and significantly reduce economic cost by significantly decreasing damage due to seismic events. The development of damage-free methods of structural response and energy dissipation are thus at the forefront of a significant amount of research. In particular, the goal is to develop low cost connections with supplemental and repeatable mechanisms for energy dissipation that do not need replacement after an event or are easy to repair/replace. This work focuses on one such type of damage free connection, the Sliding Hinge Joint (SHJ), which dissipates energy at beam-column connections through a controlled friction mechanism.

The objective of the work is the analysis, modelling and characterisation of SHJ devices based on a series of experimental results [1]. It uses a well-known, fundamental mechanics based elasto-plastic model, to describe the general but nonlinear behaviour of these devices, which have a relatively high stiffness prior to sliding and kinetic friction dissipation. In particular, these devices are characterised by identifying model parameter values specific to the wide range of friction materials and corrosion coatings that can be used leading to the creation of a general model capable of capturing a wide range of SHJ connection mechanics.

Importantly, to date, there has been no full mechanics model characterisation of performance of these connections capable of capturing any given material. In addition, the impact of coating

* Corresponding author.
E-mail address: Gregory.macrae@canterbury.ac.nz (G.A. MacRae).

http://dx.doi.org/10.1016/j.engstruct.2017.02.070
0141-0296/© 2017 Elsevier Ltd. All rights reserved.

materials on dynamic or quasi-static performance has not been measured or modeled. This study addresses these issues using an existing experimental data set and develops a general model from the foundation of a well-known hysteretic mechanics model.

1.1. Sliding Hinge Joint mechanism

The SHJ, presented below in Fig. 1, is a simple device comprising a combination of plates of different materials assembled to dissipate seismic energy. It has been developed as a low-cost, efficient means to protect structures from earthquakes [2,3]. The assembly is straightforward, and friction is a function of the clamping force provided by a series of bolts and the interaction of the shim material and slotted plate. This friction mechanism enables the repeatable dissipation of seismic energy to reduce response and thus damage but keeping the structure in or near elastic domain. As a result, it provides a repeatable form of dissipation that can be used to supplement or replace sacrificial damage of the overall connection. The SHJ, sometimes also referred to as an Asymmetric Friction Connection or AFC, has been extensively tested [1–4].

More specifically, a SHJ consists of three different plates (made of steel) and two shims held together with bolts, as shown in Fig. 1. The two long plates are called the moving plate and the top plate. They are drilled, enabling them to be fixed on both sides of the beams and columns to which they connect. The slots within the moving plates enable the mechanism to slide linearly when the beam and the column move. Between those three plates, shims are placed to provide friction surfaces. The movement of the moving plate generates friction forces in the interface between the moving plate and the shims, which propagates into the ends of the mechanism (top and cap plates). Static and kinetic friction forces are thus dependent on the shim materials used, any corrosion or other coatings, bolt torque and resulting clamping forces, and construction quality. Bolt tension is a particularly sensitive parameter in determining the resulting normal force on the shim and thus the actual device dissipation force.

1.2. Applications of the Sliding Hinge Joint

Fig. 2 presents different possibilities for building structures with AFC connections on single or concentrically braced frames. For single braced frames, one of the possibilities is to place the AFC at the end of the frame (Fig. 2-1). It offers the advantage of being easily replaceable when damage occurs. The second alternative is to cut off the frame and fix the resulting pinned connection with the AFC (Fig. 2-2). For concentrically braced frames, the AFC can be placed in two basic configurations. The AFC is directly attached to the beam bottom flange, but the two configurations differ in the arrangement of the AFC. The first solution (Fig. 2-3) places the AFC in a vertical arrangement. The second configuration is a horizontal arrangement in Fig. 2-4. The beam bottom flange is slotted and braces can be welded or bolted to a vertical plate welded to a horizontal plate located below the beam; two cap plates are required to be placed above the beam bottom flange.

The typical SHJ design offers the following properties [1,4]:

- Long slots in the moving plate increase the displacement capacity.
- The bolt clamping force and thus the bolt torque applied control the friction force.
- Damage (if any) remains in the SHJ only and is not transmitted to the frames.
- The cost is low due to simple design and construction, and low cost materials

The SHJ is intended for structures that may be subject to high excitation, typically in regions with high seismicity. Finally, it should be note that there are several other methods and devices

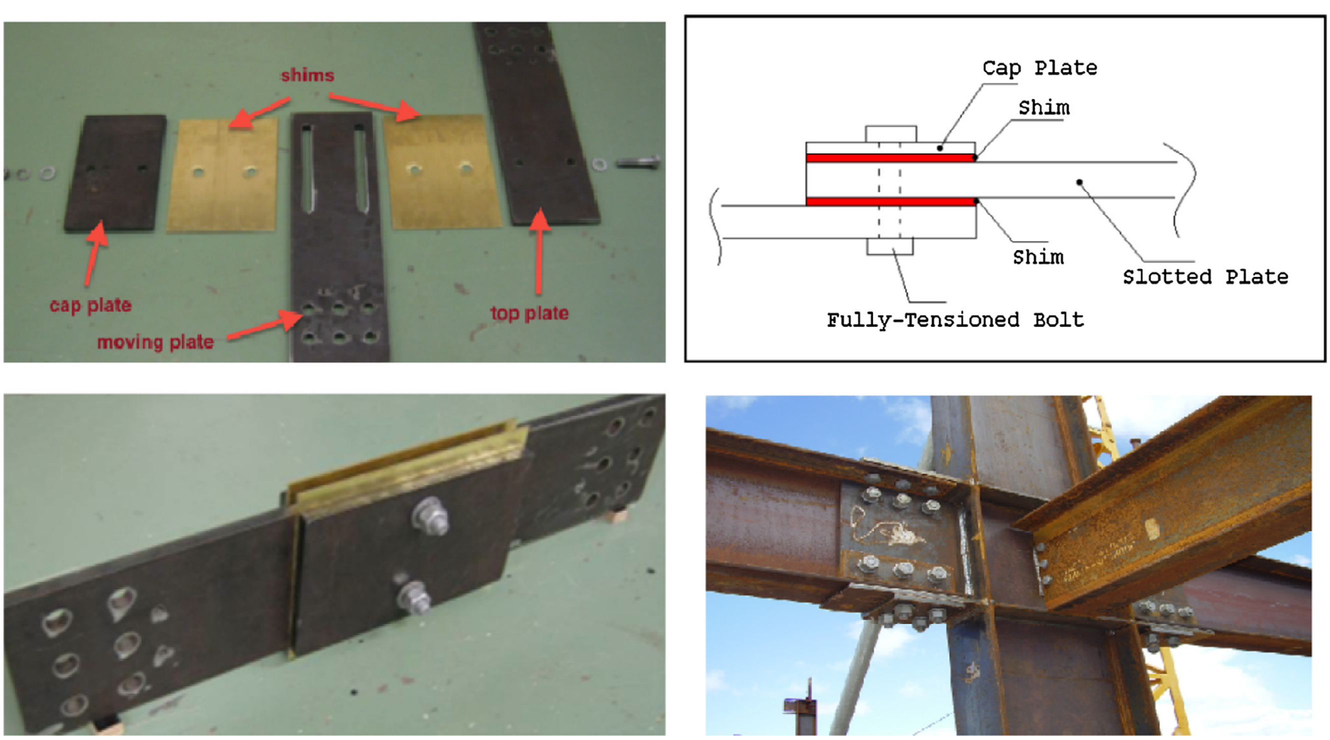

Fig. 1. Sliding Hinge Joint mechanism; disassembled device (top left), two assembled views (top right and bottom left) and column/beam connection using the design approach (bottom right) [5].